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Journal of Plant Nutrition

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713597277>

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Online Publication Date: 01 September 2005

To cite this Article Morris, D. R., Glaz, B., Powell, G., Deren, C. W., Snyder, G. H., Perdomo, R. and Ulloa, M. F. (2005) 'Leaf Phosphorus Diagnosis of Sugarcane on Organic Soils', *Journal of Plant Nutrition*, 28:9, 1511 — 1523

To link to this Article: DOI: 10.1080/01904160500202483

URL: <http://dx.doi.org/10.1080/01904160500202483>

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Leaf Phosphorus Diagnosis of Sugarcane on Organic Soils

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ABSTRACT

Most of the sugarcane (interspecific hybrids of *Saccharum* sp.) production in Florida is on organic soils. Supplemental phosphorus (P) fertilizer is often applied for optimum yields, but producers are required to reduce P levels in farm drainage waters. The objectives of this study were to relate optimum leaf P tissue concentration with yield in organic soil, and to determine optimum leaf sampling dates during the summer. Eight genotypes were planted at two locations, eight additional genotypes were planted at a third location, and eight more genotypes were planted at a fourth location. Crops were grown for three years. Measurements of leaf P concentration were repeated during growth seasons and over crop years for a total of six sampling dates at each location. Three fertilizer P treatments (0, 24, and 48 kg ha⁻¹ yr⁻¹) were applied to all genotypes at each location. Leaf samples were partitioned into early-, mid-, and late-summer dates. Early-leaf samples had the widest range in leaf P concentrations compared with mid- and late-season leaf samples. Correlation analyses of yield vs. leaf P concentration across all treatments in early- and mid-summer were statistically significant ($P < 0.05$), but coefficients were low ($r = 0.14$ and 0.26 , respectively). No consistent relationship across locations described the effect of leaf P tissue concentration on yield. Leaf P concentrations could not provide accurate P fertilization rates that will give maximum sugarcane yields and prevent over-fertilization of P. The highest potential for relating leaf P concentrations with yield appears to be from early leaf samples.

Keywords: foliar diagnosis, organic soil, phosphorus, sampling time, sugarcane

Received 1 June 2004; accepted 16 September 2004.

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INTRODUCTION

Sugarcane is grown on about 144,000 ha in south Florida and generates over a billion U.S. dollars for the economy (Izuno et al., 1999; Glaz, 1998). Most of this sugarcane is grown on highly productive Histosols. Phosphorus (P) is an important component in the fertility of these organic soils and is included in the fertilizer recommendations for high sugar yields in the Everglades Agricultural Area (EAA) (Sanchez, 1990). The Diagnosis and Recommendation Integrated System (DRIS) has been used to evaluate fertilizer needs for sugarcane. Elwali and Gascho (1984) applied P and potassium (K) to sugarcane at rates ranging from 0 to 51 and 0 to 560 kg ha⁻¹, respectively, and used leaf samples to determine DRIS indices for nine essential nutrients. To check those indices, they split individual plots and applied optimum (DRIS) fertilizers to the half-plots. They concluded that applying the appropriate balance of nutrients could improve sugar yields. However, their system requires analysis for multiple nutrients that may not be required by the crop at time of sampling. Consequently, most EAA sugarcane growers base their P fertilizer applications on soil test results independent of DRIS.

Another reason for not using a leaf-diagnosis system to determine fertilizer requirements is the high native fertility of organic soils. Some organic soils in the EAA may mineralize as much as 72 kg P ha⁻¹ yr⁻¹ depending on the organic-matter content (Diaz et al., 1993). Sugarcane has not always responded to triple superphosphate fertilizer, applied at planting, at rates ranging from 0 to 343 kg P ha⁻¹ (Elwali and Gascho, 1983; LeGrand and Thomas, 1963; LeGrand et al., 1961). Also, sugarcane plants remove about 40 kg P ha⁻¹ in top growth at harvest (Coale et al., 1993). However, it is difficult to predict soil P available to plants, due to variations in soil chemical reactions, weather patterns, and other factors that affect plant growth. Without precise information, many producers apply fertilizer according to soil test recommendations based on water and acetic acid extractable P in order to ensure P is not limiting sugarcane yields.

Growers must also ensure that excess P is not applied, because excess P in drainage water from the soil is regulated by state agencies. Producers are required to reduce the P levels in water by 25% from a baseline mean (using 1978–1988 data) and pay a land use tax of \$61.50 ha⁻¹ (Coale et al., 1993). In addition, best management practices to reduce P levels in farm drainage water are required to prevent further penalties (Anderson and Flaig, 1995). A more precise method to monitor P nutrition of sugarcane would assist growers in meeting P-reduction goals without risking reduced yields.

Leaf diagnosis for specific nutrient elements has previously been considered as a means to identify deficiencies and excesses of P in mineral soils (Samuels, 1969). Sufficiency concentrations in the leaf tissues have been determined as 1.8 to 3.5 g P kg⁻¹ dry tissue (Anderson and Bowen, 1990; Mills

and Jones, 1996). Sufficiency leaf tissue levels for organic soils have not been reported.

In mineral soils, leaf P concentration depends on many environmental factors, of which moisture and age are the most important (Clements, 1964). Leaf P concentration decreases as soil moisture declines and as the plant ages. In south Florida, organic soils are irrigated throughout the year using sub-surface irrigation from interconnected canals, so moisture deficits there are probably not as important a factor as in mineral soils in other parts of the world. The main determinant of leaf P variability in plants grown in similar organic soil environments is likely age of plant (time of leaf sampling). The objectives of this study were to relate optimum leaf P tissue concentration and yield in organic soil, and to determine optimum leaf-sampling dates during the summer.

MATERIALS AND METHODS

Four field sites were selected in the sugarcane production region of the EAA. The first site was at 20 Mile Bend Farm (20MB) of Sugar Farm Cooperative, Eastern Division, which is about 12 km west of West Palm Beach, FL. Sites 2 (OK1), 3 (OK2), and 4 (OK3) were at the Okeelanta Corporation, which is about 6 km north of the southern border of Palm Beach County, FL. Site 1 contained a Terra Ceia muck soil (euic, hyperthermic Typic Haplamedisaprist), while sites 2, 3, and 4 contained a Dania muck soil (euic, hyperthermic shallow Lithic Haplasaprist). At each site, a three (P fertilizer rate) by eight (sugarcane genotypes) factorial experiment with four replications was conducted. Phosphorus fertilizer was applied at rates of 0, 24, and 48 kg P ha⁻¹ yr⁻¹ as triple superphosphate. The 24 kg P ha⁻¹ rate was chosen as the median rate because it is often the recommended rate based on soil-test results and was also a median of recommended plant-cane rates for the four locations of this study (Sanchez, 1990). The 0 and 48 kg P ha⁻¹ rates were used to create a wide range of P availability in the soil over a three-yr period. Each experiment was harvested three times (plant-cane, first-ratoon, and second-ratoon) except OK1, which included only two harvests (plant-cane and first-ratoon).

Twenty-four sugarcane genotypes and cultivars were planted. At 20MB and OK1, cultivars grown were 'CL 72-321,' 'CL 61-620,' 'CP 72-2086,' 'CP 73-1547,' 'CP 80-1827,' 'CP 81-1254,' 'CP 85-1308,' and 'CP 85-1382.' At OK2, cultivars grown were 'CL 73-239,' 'CP 70-1133,' 'CP 72-1210,' 'CP 78-1628,' 'CP 80-1743,' 'CP 84-1198,' 'CP 85-1432,' and 'CP 85-1491.' At OK3, cultivars grown were 'CP 88-1508' and 'CP 88-1762,' and genotypes grown were 'CP 90-1113,' 'CP 90-1428,' 'CP 90-1464,' 'CP 90-1535,' 'CP 90-1549,' and 'CP 92-1435.' These cultivars comprised about 81% of Florida's sugarcane (Glaz, 1998), and the genotypes were promising candidates for commercial release in Florida.

Table 1
Dates of planting, fertilizing, harvesting, and leaf sampling¹

Location	Planting	Fertilizing	Harvesting	Leaf sample	Leaf sample	Leaf sample
Plant-cane						
20MB	12/—/93 ²	12/—/93	02/07/95	06/30/94	08/08/94	—
OK1	11/23/93	11/23/93	01/10/95	06/28/94	07/20/94	08/22/94
OK2	12/29/94	12/29/94	12/14/95	05/22/95	07/27/95	—
OK3	11/22/95	11/22/95	01/21/97	04/16/96	08/19/96	—
First-ratoon						
20MB	—	04/10/95	11/28/95	05/24/95	07/26/95	—
OK1	—	04/18/95	01/22/96	05/22/95	07/27/95	—
OK2	—	03/26/96	12/10/96	04/16/96	05/29/96	07/08/96
OK3	—	06/24/97	12/27/97	06/23/97	07/15/97	—
Second-ratoon						
20MB	—	03/21/96	10/10/96	04/15/96	05/28/96	—
OK1	—	04/02/96	—	04/16/96	—	—
OK2	—	06/24/97	10/13/97	05/14/97	06/23/97	07/15/97
OK3	—	04/01/98	10/29/98	05/21/98	07/07/98	—

¹Dates are presented as month/day/year.

²Day of planting was not recorded.

Fields were prepared by discing and furrows made with a furrow plow for planting. Plots were four rows wide and 10.7 m long, with 1.5 m between rows. Fertilizer P was applied in the furrow at planting for plant cane and top-dressed in a band near the row for ratoon crops (Table 1). Along with P, all plots were fertilized the first year with a commercial mixture of manganese (Mn), copper (Cu), zinc (Zn), and boron (B) at elemental rates of 5, 2, 2, and 1 kg ha⁻¹, respectively. Potassium chloride was applied each year at a rate of 186 kg K ha⁻¹. Due to high rates of N mineralization in the organic soils, N fertilizer was not applied (Glaz, 1998).

Leaf sampling was scheduled to provide early-, mid-, and late-sampling dates during the summer, which correspond to the first, second, and third leaf-sample dates, respectively (Table 1). Due to time constraints of sampling remote locations, samples were taken at early- and mid-sampling dates at all locations, and a late-leaf sampling was taken from plant-cane at OK1, first-ratoon at OK2, and second-ratoon at OK2. After leaves were sampled once in the second-ratoon crop at OK1, the experiment was mistakenly fertilized by a commercial applicator. The fertilizer applications in the first-ratoon crop at OK3 and in the second-ratoon crop at OK3 were late relative to the first sampling dates in those years. For these reasons, the later leaf samples were expected to better reflect the relationship between leaf P concentration and plant yield.

Ten leaves immediately under the top visible dewlap (first leaf under the uppermost fully expanded leaf), including midribs, were collected from each of 10 randomly selected plants in each plot. This leaf sample is consistent with leaf sampling in Puerto Rico (Samuels, 1969). Leaf sampling took place between 10 a.m. and 4 p.m. each day. Sampling of leaves between 6 a.m. and 10 a.m. has been recommended to standardize the procedure in case there is moisture stress in the cane field (Samuels, 1969). Under non-stressed conditions, as occurred in our experiments due to subsurface irrigation, leaf-moisture-induced diurnal P changes were less of a concern. Leaves were dried at 60°C and ground in a stainless steel mill to pass a 1-mm screen. Phosphorus concentration in ground leaf tissues was determined by acid digestion (Lowther, 1980) followed by colorimetric determination of P in the digest using molybdenum blue (Murphy and Riley, 1962).

Sugarcane harvest on the dates listed in Table 1 consisted of randomly cutting 10 stalks at ground level from one of the center rows of each plot and weighing them. Stalks were then crushed for juice quality analysis. Juice was weighed separately from bagasse (fiber remaining after juice extraction). Brix and polarization measurements on juice were used to calculate sucrose content according to the method described by Chen (Chen, 1985). Stalk counts were taken to estimate total fresh cane and sugar yields during the summer growing seasons prior to each harvest.

To determine initial fertility levels in the fields, soils were sampled from the 0 to 20 cm horizon at 20MB, OK1, and OK2 within two weeks after planting from two of the eight plots in each replication that were not fertilized with P. At OK3, samples were randomly taken before planting from the top 20 cm of soil. All soil samples were analyzed for pH (water) and extractable P (water and acetic acid) (Sanchez, 1990; Korndorfer et al., 1995).

Cane (fresh), sugar yields, and leaf P concentration were analyzed by the general linear regression method rather than by analysis of variance because there were missing values in the data set (SAS, 1990). The model tested was a factorial arrangement of treatments (genotype and P rate) within a randomized complete block (replications) with split-split (harvest within location) plots. Leaf P concentration was analyzed similarly except split-split-split plots (sample time within harvest and location) were included in the model. Correlations between cane yield and leaf P concentration were calculated for sample means (SAS, 1990). If a cane yield mean did not have a corresponding leaf-sample mean or visa versa, the sample was not included in the correlation analysis. Statistical significance was set at $P \leq 0.05$.

RESULTS AND DISCUSSION

Results from analyses of variance for cane and sugar yields were similar. Of the three-way interactions, only the P rate \times location \times harvest was statistically significant. All the two-way interactions involving P rate were significant, as well as

genotype and harvest main effects. When the data were analyzed separately for each location, genotype \times P rate interaction was not significant at any location.

With leaf P concentration, neither the five-way nor any of the four-way interactions were significant. Although genotype main effect was significant, the two- and three-way interactions with P rate were not significant. Because genotype was not an important interactive factor in the effect of P-fertilizer rate on cane yield and leaf P concentration, our discussion will focus on the interactions between location, harvest, and P rate for cane yields and the interactions between location, harvest, leaf sampling time, and P fertilizer rate for leaf P concentration. These results conform to those found in the literature for mineral soils in that genotypes often do not have a strong interactive effect in determining the P nutrition of the plant (Samuels, 1969; Baver and Humbert, 1956; Evans, 1967).

Phosphorus was deficient at three of the four locations, as indicated by the increasing cane yields with increasing fertilizer P applications (Figure 1). Optimum P fertilizer rate for cane fresh yield was about 24 kg P ha⁻¹ at all 20MB harvests, OK2 second-ratoon, and OK3 plant-cane and second ratoon harvests. At OK2 plant-cane and first-ratoon harvests and at OK3 first-ratoon harvest, cane yields were increased with supplemental P up to 48 kg ha⁻¹. Phosphorus was determined not to be deficient at OK1 at any harvest, because cane yields were not increased with increasing P fertilizer application rates.

Optimum date of sampling, as indicated by the highest leaf P concentration resulting from fertilizer P application, was not consistent across locations and cane harvests (Figure 2). For example, at 20MB, the maximum leaf P concentration was 1.4 and 1.6 g P kg⁻¹ for plant-cane at early- and mid-summer leaf-sampling dates, respectively. At OK3 maximum leaf P concentration was 2.2 g P kg⁻¹ at the early-summer leaf-sample date, and the leaf sample had an increase in leaf P concentration as the fertilizer rate was increased from 0 to 48 kg P ha⁻¹ for the mid-summer leaf-sample date. For first-ratoon at 20MB, leaf P concentrations were not significantly increased with increasing fertilizer P rates for early-summer leaf samples, and highest leaf concentrations were 1.2 g P kg⁻¹ for mid-summer leaf samples. The second-ratoon early-summer sample at 20MB had increased leaf P concentration with each application of fertilizer P, but the second-ratoon mid-summer leaf sample did not have a significant leaf P concentration response to fertilizer P.

Anderson and Bowen (1990) and Mills and Jones (1996) reported optimum P concentrations of from 1.8 to 3.5 g P kg⁻¹ dry leaf tissue (includes midrib) for sugarcane growth. Leaf P concentrations in this study were often borderline to deficient based on those values (Figure 2). Only the second-ratoon early-summer leaf sample at 20MB, second-ratoon early-summer leaf sample at OK1, and the plant-cane early- and mid-summer leaf samples at OK3 had values greater than 1.8 g P kg⁻¹.

Some P concentrations were at critical levels (the transition zone between optimum and deficient leaf P for increased plant yield) of less than 1.0 g P

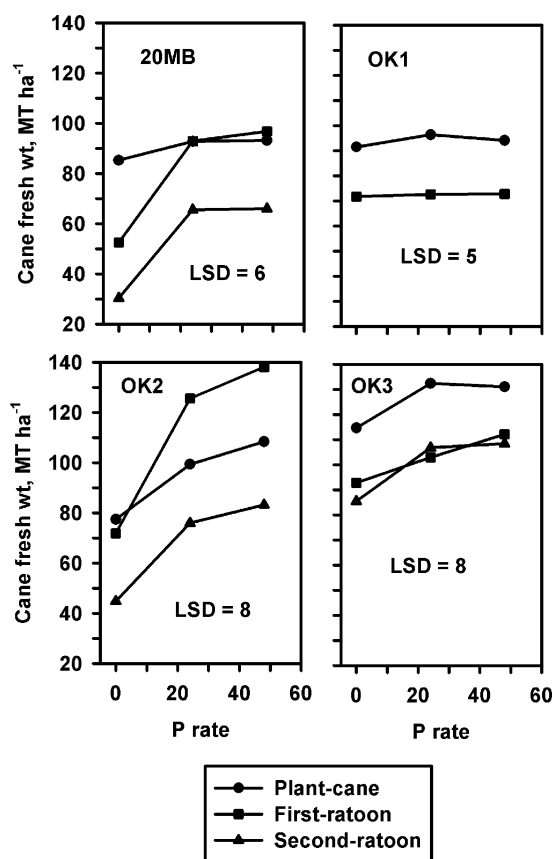


Figure 1. Sugarcane fresh yield from P fertilizer application at three locations. Overall $LSD_{(P=0.05)}$ for comparing means across locations, plant harvest, and P rates is 7 MT cane wt ha⁻¹.

kg⁻¹ at all P rates (Anderson and Bowen, 1990). At 20MB first-ratoon early-summer, OK1 plant-cane late-summer, OK2 first-ratoon late-summer, and OK3 first-ratoon early-summer there were no significant leaf P responses to fertilizer P treatment, and leaf P concentrations averaged 0.9, 1.0, 1.0, and 1.1 g P kg⁻¹, respectively.

To further investigate the relationship between leaf P content and cane yields, correlation analysis was conducted. Across all locations and harvests, cane yields and leaf P concentration were significantly correlated in the early- and mid-summer leaf samples ($r = 0.14$ and 0.26 , respectively) (Table 2). However, the low correlation coefficients minimize the practical utility of these significant correlations (Figure 3). For all data in early- or mid-summer, there was a great deal of scatter in the data points, and a leaf concentration of 1.0 g

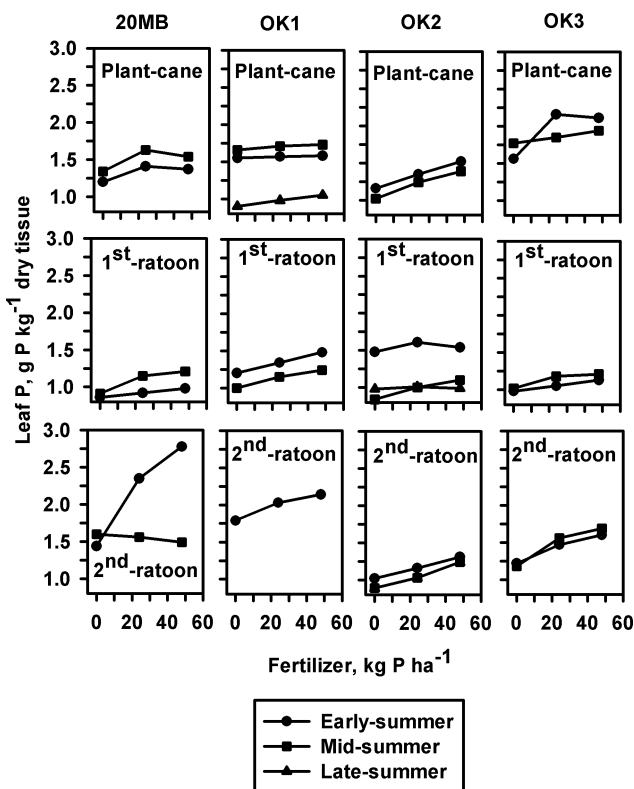


Figure 2. Sugarcane leaf P content from P fertilizer application at four locations and three plant harvests. Overall LSD ($P=0.05$) for comparing means across locations, plant harvest, sampling time, and P rates is 0.14 g P g⁻¹ dry tissue.

P kg⁻¹ tissue sometimes produced the same cane yield as a leaf concentration of 2.0 g P kg⁻¹ tissue. The plot for each leaf-sample time across all locations and harvests reveals linear responses only in the first two leaf-sampling dates (early-summer for plant-cane and first-ratoon cane), with no other mathematical trends significant (Figure 3). However, when the data set was partitioned by harvest for each sampling date, there was a significant correlation with plant-cane and first-ratoon at the early- and mid-summer leaf samples; correlations ranged between 0.23 and 0.64 (Table 2). A plot of that data does not reveal an optimum leaf P concentration (early-summer sample for plant-cane and first-ratoon cane) (Figure 3). A further partitioning into harvests at each location for each leaf-sampling date does not show any significant trend in the data except one correlation coefficient of 0.79 at 20MB for the second-ratoon early-summer leaf sample. No consistent correlation trends within locations were detected.

Table 2

Correlation analyses for leaf P concentration vs. cane yield at three leaf-sampling dates

Data set	Early-summer leaf sample		Mid-summer leaf sample		Late-summer leaf sample	
	n	r	n	r	n	r
All data	264	0.14 ^{*1}	264	0.26 [*]	72	0.09 ns
Plant-cane (PC)	96	0.64 ^{**}	96	0.47 ^{**}	24	0.36 ns
1st-ratoon (FR)	96	0.26 ^{**}	96	0.23 [*]	24	0.02 ns
2nd-ratoon (SR)	72	-0.05 ns	72	0.09 ns	24	0.59 ^{**}
20MB × PC	24	0.22 ns	24	0.21 ns	—	—
20MB × FR	24	0.31 ns	24	0.59 ^{**}	—	—
20MB × SR	24	0.79 ^{**}	24	-0.25 ns	—	—
OK1 × PC	24	0.12 ns	24	0.11 ns	24	0.36 ns
OK1 × FR	24	-0.02 ns	24	0.38 ns	—	—
OK1 × SR	—	—	—	—	—	—
OK2 × PC	24	0.50 [*]	24	0.68 ^{**}	—	—
OK2 × FR	24	0.23 ns	24	0.54 ^{**}	24	0.02 ns
OK2 × SR	24	0.45 [*]	24	0.59 [*]	24	0.59 ^{**}
OK3 × PC	24	0.31 ns	24	-0.06 ns	—	—
OK3 × FR	24	-0.11 ns	24	0.41 ns	—	—
OK3 × SR	24	0.09 ns	24	0.16 ns	—	—

^{1,*} and ^{**} denote significance at the 0.05 and 0.01 level, respectively; ns denotes non-significance at the 0.05 level of probability.

Two additional observations can be made from the plots of cane yields vs. leaf P concentrations (Figure 3). The first is that the range in leaf P tended to decrease over the season. Ranges in early-, mid-, and late-leaf samples were 0.5–3.4, 0.6–2.4, and 0.7–1.3 g P kg⁻¹ tissue, respectively (Figure 3). An explanation could be that P was less available later in the season due to uptake of readily available fertilizer earlier in the season. These results suggest that future studies should focus on sampling earlier in the season to obtain wider ranges in leaf P concentrations.

The second observation is that the early-summer second-ratoon sample tended to have a greater range of leaf P concentration than the range from early-summer plant-cane and first-ratoon samples (Figure 3). The ranges for early-summer plant-cane, first-ratoon, and second-ratoon were 1.0–2.5, 0.5–1.9, and 0.8–3.4 g P kg⁻¹ tissue, respectively. This observation suggests there were more excesses and deficiencies of P in the second-ratoon plots due to annual P application treatments. Even with the large range in leaf P concentrations across locations, the best correlations between leaf P and cane yield were obtained from the second-ratoon harvest. Among second-ratoon harvests, four correlations of seven were significant (20MB × SR for early-summer and OK2 × SR for early-, mid-, and late-summer) (Table 2).

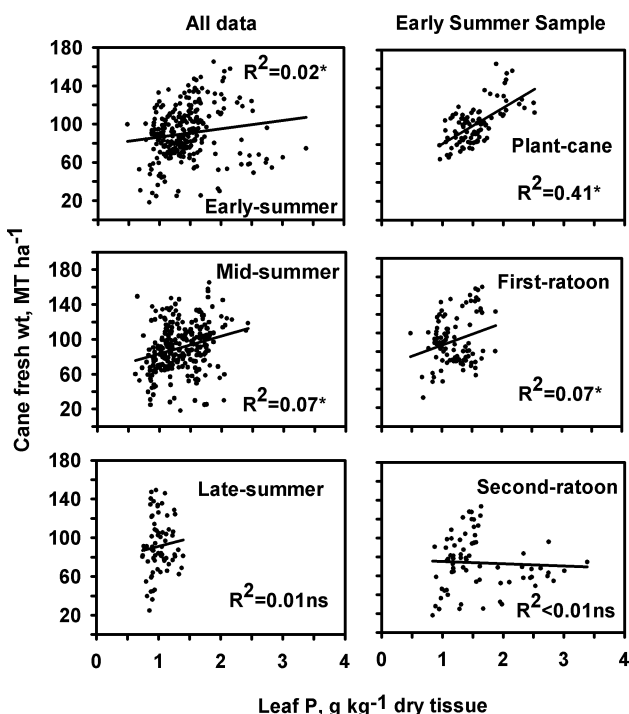


Figure 3. Sugarcane fresh yield vs. leaf P concentration at three sampling dates for all data and for three plant harvests.

Leaf diagnosis is of little use if it is not related to plant yields (Samuels, 1969). Plants nutrient content and yield may be related by two mathematical models: limiting factors (Leibig's law) or diminishing returns (Mitscherlich's law) (Samuels, 1969). According to the former model, plant yield is directly proportional (linear response) to nutrient content in the plant. According to the latter model, plant yield response diminishes (quadratic response) as plant nutrient content reaches adequate supply. Even though no single theory describes all relationships between leaf nutrient analysis and yield (Samuels, 1969), plots of plant yields vs. leaf-nutrient concentrations in this experiment tended to be linear (all data for early- and mid-summer and early-summer for plant-cane and first-ratoon) and reflect the former response mechanism (Figure 3).

Imbalances in nutrients such as N could have occurred in our experiment. For example, Lunin and Aughtry (1954) applied up to 112 and 74 kg ha⁻¹ of N and P, respectively, to sugarcane. Cane yields with higher rates of N had lower P concentrations in leaves. Because organic soil in the EAA may release as much as 1200 kg N ha⁻¹ yr⁻¹ (Terry, 1980), there may have been a negative effect on leaf P concentration from high N levels in the soil. The exact relationship

Table 3

Soil test results at planting and recommendation for plant-cane from four locations

Location	pH	Extractable P (H ₂ O), kg ha ⁻¹	P recommendation ¹ based on P (H ₂ O) extraction, kg ha ⁻¹	Extractable P (CH ₃ CO ₂ H) ² , kg ha ⁻¹
20MB	5.4	10.9	0	17.9
OK1	6.7	3.2	30	31.6
OK2	6.3	2.2	34	22.5
OK3	6.6	1.0	37	25.0

¹From Sanchez (1990).

²Recommendations for P have not been tested.

between leaf P concentration, plant-available N, and crop yields will require further investigation.

Based on soil-sample analysis (water extractable P), Florida sugarcane recommendations were that supplemental P fertilizer was needed at all locations except 20MB (Table 3). Soil test results accurately predicted plant-cane need for fertilizer P in two (OK2 and OK3) of the four locations (Figure 1). Korndorfer et al. (1995) applied 0 to 98 kg P ha⁻¹ to sugarcane at four sites and compared water extractable P with acetic acid extractable P for determining P fertilizer rates for optimum sugarcane yields. They found acetic acid extractable P had a higher correlation ($r = 0.63$, $P < 0.05$) with cane yields than water-extractable P ($r = 0.39$, $P < 0.05$), and that acetic acid-extractable P levels ranged between 0–14, 14–59 and >59 kg P ha⁻¹ for low, medium, and high soil P, respectively. All our acetic acid-extractable P values were within the medium range (Table 3), indicating that fertilizer P application would likely increase plant-cane yield at all locations. Korndorfer et al. (1995) did not provide fertilizer P recommendations for acetic acid-extractable P levels in soil. However, yield prediction accuracy was the same as with water-extractable soil P in that plant-cane responded to fertilizer in two (OK2 and OK3) out of four locations (Figure 1). Based on soil-test P results from our study, it appears that soil testing may be reliable only 50% of the time in predicting fertilizer P requirement of sugarcane at planting, regardless of soil test procedure.

Gascho and Kidder (1979) evaluated soil tests, fertilizer P applications, and sugarcane yields at three locations over a two-year period. The fertilizer P required to raise the soil-test levels to a given value was different for each site. They recommended that soil-test results along with crop yield on a given soil type should be evaluated over a number of years. Based on our data, other factors beside soil type may need to be investigated because OK1, OK2, and OK3 had the same soil type.

In regards to foliar diagnosis, even though cane yield from the plant-cane harvest tended to reach an optimum (20MB and OK3), increased up to maximal (OK2), or was already at optimum (OK1) with increasing fertilizer P rates (Figure 1), leaf P concentrations in plant-cane for all leaf-sampling dates were less than optimum ($< 1.8 \text{ g kg}^{-1}$) (Anderson and Bowen, 1990; Mills and Jones, 1996) when fertilizer P was applied at three out of four locations (20MB, OK1, and OK2) (Figure 2). Leaf P diagnosis appears to predict optimum levels approximately 25% of the time, and, as with fertilizer soil tests, may also have to be evaluated over a number of years for each soil type or field.

CONCLUSIONS

Producers in the EAA are required by law to reduce P levels in farm drainage waters. However, neither leaf diagnosis nor soil testing provide accurate information to determine P fertilization rates in organic soils that will give maximum sugarcane yields without increasing potential for P losses. Other methods need to be devised to prevent excess P fertilization. Evaluation of a more thorough schedule of leaf P determination within soil types, along with more frequent soil testing, may be needed to predict P applications that optimize crop yield and minimize P discharge in drainage waters. Early-season leaf sampling appears to have the greatest potential for determining the relationships between leaf P concentration and crop yield.

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